A REVIEW

OF THE

REPORT UPON THE PHYSICS AND HYDRAULICS

OF

THE MISSISSIPPI RIVER.

PREPARED BY

CAPT. A. A. HUMPHREYS AND LIEUT. H. L. ABBOT,
CORPS OF TOPOGRAPHICAL ENGINEERS, UNITED STATES ARMY.

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EDWIN HALE ABBOT, A. M.

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CROSBY AND NICHOLS,
117 WASHINGTON STREET.
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THE MISSISSIPPI RIVER;

UPON THE

PROTECTION OF THE ALLUVIAL REGION AGAINST OVERFLOW;
AND UPON THE DEEPENING OF THE MOUTHS;

BASED UPON

SURVEYS AND INVESTIGATIONS MADE UNDER ACTS OF CONGRESS.

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REVIEW.

Report upon the Physics and Hydraulics of the Mississippi River; upon the Protection of the Alluvial Region against Overflow; and upon the Deepening of the Mouths: based upon Surveys and Investigations, made under the Acts of Congress directing the Topographical and Hydrographical Survey of the Delta of the Mississippi River, with such Investigations as might lead to determine the most practicable Plan for securing it from Inundation, and the best Mode of deepening the Channels at the Mouths of the River. Submitted to the Bureau of Topographical Engineers, War Department, 1861. Prepared by Captain A. A. Humphreys and Lieutenant H. L. Abbot, Corps of Topographical Engineers, United States Army. Philadelphia: J. B. Lippincott & Co. 1861. 4to. pp. 456; with an Appendix, pp. 146, and 20 Plates.

The Mississippi River, above the mouth of the Missouri, flows, like many other large rivers, between bluffs and permanent banks with a gentle current and a clear tide. Below the mouth of the Missouri, its whole character changes, and it becomes a turbid, boiling torrent, tremendous in volume and force. Henceforth it pursues a devious course for thirteen hundred miles, washing away banks and islands here, rebuilding them there, absorbing, without visible increase of size, tributary after tributary, until at last the river is itself swallowed up in the greater volume of the Gulf. Just above the mouth of the Ohio begins a great alluvial plain some fifty miles in width, which is mostly *below the level of the floods.*

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This fact has made the problem of protection against overflow the great practical question involving the prosperity of that entire region.

The river was first settled near its mouth, at New Orleans and Natchez. The high bluff on which Natchez is built, being one hundred and fifty feet above the river, effectually relieves that city from all danger of inundation. But at New Orleans the very condition of existence is artificial protection against this danger. Here then, at the very outset, began the great struggle which, throughout the alluvial region, has made the history of civilization the history of river-protection. From 1727, when, in November, Governor Perrier announced that the first levee at New Orleans, a dike 5,400 feet long and eighteen feet wide at top, was completed, down to the present day, when more than a thousand miles of levees line the banks, the constant object of legislation and private care has been to restrain this terrible friend within his proper bed. The great prominence of this question of protection has carried it into local politics, and made it an issue on which party success has depended. In Louisiana the Outlet party and the Levee party have fought, in caucus and mass meeting, the same battle for power which is fought elsewhere under other names. The statute-books of the River States are full of laws on the same subject, and the ever-present danger causes a never-ceasing agitation.

The history of this question furnishes one among the many proofs of the necessity of a great central government and of union among the States. Momentous as is the decision, vast as are the consequences involved therein, indispensable as united action is to success, the River States have never been able to agree upon the same policy, or to join in making the needed investigations, and using their results. Although these embankments have now been building for nearly one hundred and fifty years, want of concert, and of that knowledge which could have been gained by concerted action alone, has rendered them ineffective. The consequence has been, that one district has been submerged through the faulty character or execution of the laws in another district, and the want of success has conspicuously exhibited the misdirection

and division of effort. Millions of dollars have been uselessly expended already, and now a sum is required for the thorough protection of the valley from overflow, which, though great, "does not, probably," in the pointed words of the Report, "largely exceed the amount which has actually been spent in abortive attempts." All the violent upheavals of political strife, and even the very instinct of self-preservation, have been insufficient to bring into harmonious action three or four independent States, while all the divided efforts of their State engineers have entirely failed to devise any sure plan. It was not until the United States government undertook the investigation that the first conditions of success were ascertained, or even the first step taken toward a correct solution of the problem. What clearer illustration of the delusion which now overclouds the Southern Mississippi Valley is needed than is afforded by this fact? The beneficent action of that government alone, which they are now striving to cast off, has entirely solved for them the problem of river protection, which is to them the very issue of life and death.

In September, 1850, the federal government, by an act approved September 28, granted to the several States on the Mississippi all the swamp and overflowed lands within their limits remaining unsold, in order to provide a fund to reclaim the districts liable to inundation. The States of Louisiana, Mississippi, Arkansas, and Missouri soon began vigorously to avail themselves of this grant by organizing under it the necessary offices and commissions. The people at the mouth and in the lower valley of the river, alarmed lest the effect of the reclamation of vast swamps above should be to increase the floods below, and fearing the results for themselves, invoked the aid of the general government in the necessary surveys for investigating the matter. From this movement the Delta survey took its origin. The vast task has at length, after many years of intense labor, been accomplished, and its fruits are now before us in the very elaborate and masterly Report which is the subject of our review.

The Report has been prepared by Captain A. A. Humphreys and Lieutenant H. L. Abbot, of the Corps of Topographical Engineers, United States Army. From the beginning, the

work has been in charge of Captain Humphreys, a name well known to every one acquainted with American science, and which is associated with, literally, almost every important scientific work undertaken by our government during the last quarter of a century. He began field operations in November, 1850, but was compelled by severe illness, occasioned by exposure and overwork in the survey, to suspend them in the summer of 1851. His health was so shattered that he was long an invalid. Upon his recovery he was overwhelmed with other professional duties, — among which may be named the general charge of all the Pacific Railroad Surveys, — so that the river work was not resumed until the summer of 1857. Lieutenant Abbot, who had previously been engaged, under Captain Humphreys's orders, upon the Pacific Railroad Surveys, was then, at Captain Humphreys's request, assigned to duty upon the Delta Survey. In November, 1857, Lieutenant Abbot proceeded to the river to organize the parties, and prosecute the surveys and investigations. Since that date the Delta Survey has proceeded without interruption, and the amount of field and office labor performed is absolutely astonishing. The wide region covered by the plan, the multitude and variety of observations required, the precision and skill demanded in them, and, above all, the genius which could first devise the scheme of field observation, then execute it successfully, and finally interpret the enormous mass of facts and data, and evolve from the chaos the beautiful laws of science and the simple practical conclusions contained in the Report, fill the reader with wonder. Of the office work, and Lieutenant Abbot's share in it, Captain Humphreys speaks as follows, in his letter to the Bureau: —

"This work, which was in fact the preparation of the Report, was performed by myself and Lieutenant Abbot. It involved an amount of labor and study which will not perhaps be fully appreciated even by professional persons. Devoted to the task, Lieutenant Abbot brought to its performance great industry, energy, sagacity, and skill in analysis, the fruits of which, to be found in every part of the Report, are particularly exhibited by the chapters in which the flow of water in natural channels is treated. But a perusal of the Report will convey a more forcible impression of the extent and value of Lieutenant Abbot's labors than any terms of acknowledgment that I can use."

And finally, with a liberality only too rare among scientific men, he transmits the Report to the Bureau in the joint names of himself and Lieutenant Abbot, in the following words: —

"The association of Lieutenant Abbot with me in this duty has been of such a character that the title of the Report should bear his name as well as mine. I beg leave, therefore, to submit it herewith, to the Bureau of Topographical Engineers, as our joint Report upon the Survey of the Delta of the Mississippi River."

It is not too much to say, after a careful study of this Report, that, as a work of science, it will not suffer by comparison with any in our language, while it is in its special department without a peer, and almost without a rival. It finds the whole subject of river hydraulics a confused congeries of discordant theories and untenable hypotheses, the offspring of insufficient generalizations. It leaves it a determinate science, the result of wide observation of facts, acute and laborious combination, and rigid and logical scientific analysis. Its authors may well be proud of their work, for it places them in the front rank of scientific men, and shows them to be the discoverers of a science, the first-fruits merely of which appear in their deduction of the laws which regulate the flowage of the Mississippi.

The typographical execution of the book is very neat. It is a pleasure to see the Report presented to the public in a dress worthy of its contents, and in striking contrast to the slovenly appearance of many of our government works. The paper is fine, white, and thick; the type, large, clear, and fresh; the page, quarto, with wide margin, and side-notes so excellently arranged in full-faced type as partially to compensate for almost the only fault which can be found with the book, the absence of an alphabetical Index.*

Having now described the necessity and origin of the survey, and the general character of the book, we propose to give a brief analysis of its contents in the order of its chapters, before proceeding to furnish a condensed statement of its

* It is but fair to state that upon inquiry we found the sole reason of this omission to have been the pressure of military duty. Before the book had passed through the press, its authors were called to the field.

subject-matter, or adverting to the questions which it discusses, and which, of absorbing interest in the Mississippi Valley, are of much general interest to intelligent men everywhere.

Chapter I. is introductory, and supplies a full account of the geography of the river basin, which, if we exclude Russia, Norway, and Sweden, is more than equal in size to the whole continent of Europe. Facts about the tributaries of the river have been collected from every quarter, and this chapter affords immeasurably more information about the whole valley than was ever before collected. It ends with a condensed tabular exhibit of the principal hydrographical features; — a table which hereafter must be quoted in every respectable encyclopædia; for it gives a tabular statement for each great tributary, comprising a series of distances from the mouth, corresponding elevations above the sea, falls per mile, width between banks, least low-water depth on bars, range between high and low water, area of cross-section, and remarks. From these last alone we have prepared the following table for the readers of the Review, because it offers so interesting an exhibit of the dimensions of the main Mississippi, and of the relative functions of the chief tributaries. It shows that the Ohio, with much less than half the area of basin drained by the Missouri, contributes notwithstanding nearly one third more water to the volume of the Mississippi, — a striking illustration that neither the size of its basin, nor the length of its course upon the map, is any criterion of the hydrographic importance of a tributary stream.

	Area of Basin in Square Miles.	Downfall of Rain in Inches.	Ratio betw'n Downfall and Drainage.	Mean Dischar. per Second in Cubic Feet.
Ohio River, ...	214,000	41.5	0.24	158,000
Upper Mississippi River, .	169,000	35.2	0.24	105,000
Missouri River, ...	518,000	20.9	0.15	120,000
Arkansas River, ...	189,000	29.3	0.15	63,000
Red River, ...	97,000	39.0	0.20	57,000
Main Mississippi River, .	1,244,000	30.4	0.25	675,000

Chapter II. treats of the Mississippi River below the junction with the Missouri. It describes the physical features of

the river, and we shall presently draw largely upon it. This chapter is perhaps the most popularly interesting of all in the book. At its end the reader is fully possessed of knowledge of all the physical features of the river and its valley, and of all the conditions of the problem of protection against inundation.

Chapter III. describes the state of the science of hydraulics as applied to rivers, giving an outline of the history of the science, a complete chronological list of all the works on it, and a *résumé* of their contents. It sets forth all that was previously known about river hydraulics, showing it to be a mass of theories destitute of the fixed essentials of an exact science.

Chapter IV. goes on to show how facts were collected, measurements made, and results computed. The measurements were comparatively simple, yet sagaciously planned to make measurement do everything possible for it to accomplish, and their amount and labor will be referred to hereafter. The calculations were exceedingly complicated and difficult, and therefore, in the language of the Report, "to guard against any cavillings which may be directed against a process so long and intricate," all the data necessary to recompute the results are preserved in the Appendices. We venture to suggest, however, that it will be long before any one will undertake so Herculean a task.

Chapter V. takes up these facts, uses them, and gives a new system of river-hydraulics more thorough and full than has ever before been attempted. It is, indeed, a treatise which might well be republished directly from the Report as a text-book. Having been previously furnished with the data, we are now supplied in this chapter with the rules and principles of science required for the solution of the great problem of the Mississippi Valley.

Chapter VI. enters upon this work, introducing the question of protection against the floods in its double aspect, — first, how far the maximum discharge will be increased by reclaiming the swamp lands in the basin; and, secondly, how much the level of water surface will be thereby raised. It tests the various plans of protection by the touchstone thus furnished, and states the conclusions in the form of recom-

mendations. Thus the entire subject of river floods is finished.

Chapter VII. examines the Delta, applies the new process of analysis to the complicated problem presented by the Bayou La Fourche, and finally gives a well-considered and ingenious theory for the origin and growth of the Mississippi.

Chapter VIII. takes up the subject of the river-mouths and the bars; advances an entirely new theory of their origin and formation, based upon a set of observations similar in extent and thoroughness to those already mentioned; and, finally, develops plans for deepening them.

The volume ends with Appendices, containing the data on which the Report is based, and many maps and diagrams of curves, which beautifully illustrate the subject.

We now propose to notice a few of the many topics discussed at length in the Report. This is an undertaking of the greater difficulty, from the very compact style in which the Report is written, and the close compression of the matter. Even in a note there is often given information which might have been readily developed into a valuable chapter. It seems to have been the design of the authors to omit every superfluous word, and, above all things, to avoid that magniloquent rhetoric which has heretofore veiled so much ignorance in the writings about the Mississippi. It is with diffidence, therefore, that we now undertake to condense still further a treatise on hydraulics which has already passed through a literary hydraulic press.

In describing the river, we shall speak successively of the banks; the geology of the bed; the slope of the water surface; the cross-section of the river; the drainage of the basin, with the downfall of rain there; the sediment and the matter held in suspension by the water; the temperature of the air and water; the levees now existing; and, lastly, the great floods.

From Cape Girardeau to the Gulf, the river flows, as already remarked, through an alluvial region which is, for the most part, below the level of the floods. Columbus, 21 miles below Cairo, holds the first high land below the Ohio, — a bluff 200 feet above the river at high water. At this point,

the banks are only 2,240 feet apart, and Columbus is therefore a place of great military command over the navigation of the river. The bluffs at Hickman are similar, but less important; and the next high land is the range of Chickasaw bluffs, four in number. Fulton occupies the first, Randolph the second, and the great city of Memphis the fourth. They are about 150 feet above the high-water level. At Memphis the river is 3,360 feet wide. Memphis is 225 miles below Cairo; and, as none of the intermediate bluffs are much settled, or capable of being easily provisioned even if fortified, the evacuation of Columbus will practically open the river to this point. Crowley's Ridge, near Helena, about 65 miles below Memphis, is the last land on the right bank of the river above overflow. There is therefore required from this point one continuous line of levees to the mouth of the river, a distance of 806 miles. At Vicksburg, about 300 miles below Helena, the Mississippi, here 2,660 feet in width, again approaches bluffs on the left bank, and for nearly 250 miles flows near high land, which is from 100 to 300 feet above the river level. Natchez bluff is 150 feet in height, and the river here is 4,540 feet wide. Below Baton Rouge, 245 miles from the Gulf, both banks are everywhere below the high-water level.

The banks liable to overflow between Cape Girardeau and the Gulf are composed of the sediment deposited by floods, and are unsurpassed in fertility. They are highest near the water, where the largest and grossest deposit is of course made. They slope off most rapidly within a mile from the river. The slope then decreases until the swamps are reached, which are seldom more than two or three miles from the river bed. The mean slope of the banks from the river is, in the first mile, 7 feet, though it varies in different localities from 3 to 13 feet. It is, of course, greatest where the river has longest remained unchanged; and it would seem possible for natural levees to be thus formed by natural accumulation, which might eventually confine the stream in such parts of the valley within its channel. This has actually happened on the Colorado of the West. Such banks, however, if they begin to cave, lose temporarily in elevation; and with levees artificially made, this loss is of

course permanent. This natural form of the banks necessitates the construction of levees *as near to the river as consists with safety*, for the double object of reclaiming the most fertile land, and of reducing the height and consequent cost of the embankments to a minimum amount. With the present levees, the flood depth near the edge of the natural banks is from 1 to 15 feet, giving an average depth from Cape Girardeau to the Gulf of about 4 feet.

The geology of the bed next claims attention. A knowledge of the true character of the bed was of the highest importance, and had never before been experimentally determined. On it depended many practical questions, connected with the restraint of the floods. Great and successful efforts were therefore made to acquire it.

The channel of the river has heretofore always been assumed to be one excavated by itself through its own alluvion, and the whole alluvial region has been supposed to have been formed by deposits from the river during the present geological epoch. The plane of the Delta Survey forbade the admission of such an assumption without evidence, involving, as it did, the entire question of an unstable bed. The popular theory was therefore tested by careful soundings, with prepared leads, for 1,060 miles, from the mouth of the Ohio to Fort St. Philip, which is only 37 miles from the Gulf. These soundings and the examinations showed, — First, that immense beds of pure silicious sand and fine gravel, entirely free from mud and sediment, exist in various places, and grow finer as the Gulf is approached. They are found, in short, wherever the current flows too swiftly to deposit sediment, and yet not strongly enough to wash the sand away. Secondly, that where the current becomes dead, opposite caving bends and the like, the sediment is deposited in gently sloping, sandy mud banks, called willow battures, or, if on an island, tow-heads, from the growth of willows on them. This process of land formation merely puts a limit to the widening of the river in such places, but does not affect the nature of the true bottom. Thirdly, that *the true bottom*, on which rest the moving sand-banks and the willow battures, *is composed, from the mouth of the Ohio at least as far as Fort St. Philip, of one single homogeneous*

substance, a hard blue or drab-colored clay. This clay is quite different from any deposit now made by the river. As long as it remains wet, it seems nearly insoluble, and is very tenacious, resisting for years the strong current of the Mississippi. This clay does not often show itself above the low-water mark in the channel between the Ohio and Red Rivers. Below Red River it crops out in many places, and is generally distributed throughout the Delta.

The facts ascertained about this clay are of extreme value, for they prove, either that it is an alluvial deposit, or else that the thickness of the alluvial stratum of the entire valley has been greatly overestimated, and that the river is now flowing through a channel which belongs to a geological period antecedent to the present epoch. The age of this peculiar blue clay is highly important to be ascertained, and the following facts are some of those which tend to reveal it.

1. It greatly differs from any deposit now made by the river.

2. It underlies, below the sand stratum, the whole Yazoo bottom.

3. In the bluff at Vicksburg, it underlies the stratum which contains marine shells; that stratum which both Sir Charles Lyell and Dr. Harper pronounced to be eocene tertiary, the oldest tertiary stratum. Beyond question it also underlies other river bluffs also, but no examination was made for it at low water, when alone it would be visible.

4. It underlies New Orleans in strata, which alternate with sand and marine shells, for at least six hundred and thirty feet, as proved by the Artesian well there, which was carried to that depth before it was abandoned. The geological ages of the strata pierced are not well ascertained, but it is evident that none below the depth of forty-one feet from the surface, or, what is the same thing, thirty-seven feet beneath the level of the Gulf, were deposited by the river in its present state. The same age must be conceded for the channel of the Mississippi; for its clay is identical with the very lowest stratum pierced by the well.

5. It crops out under sandstone, twenty-four feet below the level of the Gulf, on the coast of Texas.

These are only some of the facts from which is drawn the inference that the bed of the Mississippi is not formed by recent deposit from its waters. Whatever may be the precise age of this clay, the facts certainly establish that its formation was long anterior to the present geological epoch. The correctness of this conclusion is almost demonstrated also by the form of the cross-section of the river. Were the bottom composed of alluvion, it would be comparatively smooth. It is really, on the contrary, exceedingly rough, full of blue-clay ridges and lumps, some of them many feet in height. The whirls which cover the surface also attest the great irregularity of the bottom, its non-alluvial character, and therefore its great antiquity.

The important bearings of this discovery may be stated as follows. The bed of the Mississippi is not made up of river deposit, accumulated by the stream in its course. The channel has not been worn by water through river mud, and is not shifting constantly, as such channels always do, and making it impossible to predict its position even a few years hence. It is, on the contrary, a vast natural canal, cut through a bed of hard, tenacious, insoluble blue clay; with a clay bottom, and walls of alternate layers of clay and pure white sand up to the level of low water. It is an enormous conduit, provided by nature to drain the valley, and nearly as fixed in its general course as if it were scooped out of rock. Into it pours the whole waste of the broad water-shed between the Rocky Mountains and the Alleghany range. The stately river, receiving what the numberless streams of its valley constantly discharge into it, bears along the entire mass of sediment which discolors its water, down into the Gulf, and there slowly builds up new land with the *débris*, but retains nothing for itself except what the floods leave upon the banks. On account of this great difference between the alluvial deposits and the channel of the river, and of the fact that the water is undercharged with sediment, — another great discovery to which we shall presently allude, — we are authorized to believe that the strength of the current will keep the channel always clear; and that, until the laws of nature change, there is no danger of any filling up of the bed by artificially reducing the flood discharge.

The banks of the Mississippi, however, although the *general* channel is thus sharply defined, are nevertheless, within certain limits, unstable and perpetually changing. The river is constantly undermining its banks in the bends, and forming new land on points throughout the whole alluvial region. The cause of this phenomenon is found in the strata of nearly pure sand which alternate with the clay through the entire valley. A change in direction of the force of the current washes away the layer of sand, and, when the river falls, the bank above soon caves from want of support. These sand strata are often below the mark of low water, a circumstance which greatly enhances the difficulty of protection. By this caving, "cut-offs" are also caused. They occur where two bends of the river approach each other, until the river cuts off the narrow neck of land and opens a new channel, which, from its greater slope, soon becomes the main channel. Since 1800 six cut-offs of this description are known to have occurred, shortening the river by about eighty miles; and many more are now imminent. The same action also produces upon the islands results quite as strongly marked. Under its influence, islands are, in many places, constantly forming, or connecting themselves with the main land, or disappearing. Fortunately, however, for the success of artificial protection from floods, this action of the river is now progressing much more rapidly in the upper part of the valley than in the lower, where it has to appearance comparatively ceased.

The next physical feature of the river to be noticed is the slope of the water surface. This diminishes as we draw near the Gulf, which exerts too important an influence upon it to be overlooked. From Natchez to the mouth, the oscillations caused by variations in discharge gradually diminish, while from that point the influence of Gulf changes grows more and more apparent. The mean level of the Gulf is obviously the datum-plane to which to refer the surface of the river. The effects of tidal oscillation, in low stages of the river, are probably felt even at Red River Landing, which is 316 miles from the mouth; while at Baton Rouge, 245 miles from the mouth, there is a mean tide of *two tenths* of a foot, though the mean tide in the Gulf is only *one foot and two tenths*. This delicate

variation, arising from so slight a tidal wave in the Gulf, 245 miles distant, and affecting the slope of so large a river, whose current, it must be borne in mind, nowhere at any time sets up stream, is an interesting proof of the quick perception of foreign influence, and the strict obedience to the minutest force, which are exhibited by river phenomena.

Prevailing winds also produce marked alterations of level in the Gulf, and consequently in the river. In January, 1852, the mean level of the Gulf was 1.5 feet lower than in September previous, and a foot lower than the mean monthly level of several other months of the year. If the change of the Gulf level is of long duration, this produces an oscillation in the river slope. Such an oscillation, happening between November 10 and 18, 1851, of 2 feet in the Gulf, was felt at New Carthage, 460 miles up the river; and at the mouth of Red River, 316 miles from the Gulf, it was 1.5 feet. Hurricanes produce still greater effects, which would be disastrous in the extreme, did they not occur from causes connected with those which occasion low water in the river.

The range of level between high and low water in the Mississippi averages about forty-five feet, until it comes within the influence of the Gulf. It then gradually diminishes to zero. At Natchez, where the variation in level is greatest, it ranges over fifty feet. Most of our readers will probably be surprised to learn that the oscillations of the Mississippi equal in range, even if they do not surpass, the famous tides in the Bay of Fundy. They are however very gradual, never exceeding in twenty-four hours a change of about three feet, and averaging only a few inches.

The value of land in the Mississippi valley depends so much upon its relative level that most cities there have a "bench-mark," a fixed and known point from which altitude is specified in deeds and conveyances. At St. Louis, the bench-mark, called "the St. Louis Directrix," which is the top of the curb-stone at the corner of Market Street and the levee, is 405 feet above the level of the Gulf, and 34 feet above the low-water river-mark of 1860. Yet in the flood of 1858, this was three feet under water. St. Louis is 1,253 miles from the Head of the Passes, the point where the mouths of

the river diverge, 17 miles above the Gulf. The mean slope, therefore, of the Mississippi from St. Louis to the Gulf, is only 0.31 of a foot, a little less than four inches in a mile, a slope certainly not great, and yet enough to give an observed mean flood-velocity of about six feet in a second, or a little more than four miles an hour.

A series of very extensive gauge-rod observations has determined the general laws of the stages of the river. They are beautifully exhibited in the Report by a plate of curves, representing the annual changes of the level through observed periods. These curves show, —

1. That the mean annual succession of stages differs little from the Ohio to the Gulf.

2. That there are three great rises, — in winter, spring, and summer, respectively.

3. That the river annually is highest at the end of March, then subsides, until, swelled by the early summer rains, it rises in June; then rapidly falls, until it attains its lowest point in October; and then again rises, more rapidly than at any other season, until January and February, when it is checked by the freezing of its tributaries until the commencement of the March rise.

4. That the river is above the mid-stage for seven months, from the latter part of December to the latter part of July, and below it for the rest of the year.

These are only a few of the interesting results indicated at once to the eye by these curves.

By cross-sections of the river, the mean high-water areas, the mean mid-channel depths, and the mean high-water widths, have been ascertained with approximate correctness. As the contributions of the great tributaries affect the dimensions of the main river, the results are computed for four divisions of the valley, as shown in the following table, which we copy from the Report: —

Mean Dimensions of Cross-Sections of the Mississippi River.

Locality.	High Water.			Low Water.		
	Area. Sq. Feet.	Width Feet.	Maxm. Depth. Feet.	Area. Sq. Feet.	Width Feet.	Maxm. Depth. Feet.
Ohio River to Arkansas River,	191,000	4,470	87	45,000	3,400	49
Arkansas River to Red River,	199,000	4,080	96	54,000	3,060	56
Red River to Bayou La Fourche,	200,000	3,000	113	100,000	2,750	78
Bayou La Fourche to Head of Passes,	199,000	2,470	129	163,000	2,250	114

The drainage of the river basin cannot be comprehended without understanding its relation to the fall of rain there. To ascertain with precision the fall of rain throughout the Mississippi valley demands much more labor than has yet been expended upon the subject. All the information, however, which has been collected, including three years more of observations than have been heretofore accessible, has been collated and tabulated into the only satisfactory rain-chart ever made for the valley. Previous charts undertook to delineate the exact extent of each rain district. This map, by showing precisely how much is really known, throws discredit upon such extensive generalizations. Although this is frankly acknowledged to be incomplete, it claims to be an approximation sufficiently exact for the purposes of the Report. The relation of downfall to drainage has never been determined so accurately for any large river before; while for no river, and not even for any small stream, has the discharge ever been ascertained with even an approach to the fulness and precision with which it has now been computed for the Mississippi. This computation has heretofore been impossible, for the double want of wide observation, and of knowledge of the true law which governs the flow of water in natural channels. It is an honor to American science, that, owning the finest watercourse in the world, it has proved itself competent to appreciate and measure its magnificent possession.

The area of the basin of the entire Mississippi valley is 1,256,050 square miles. The mean yearly amount of rain therein is 84,400,000,000,000 cubic feet. The annual discharge of the Mississippi is 19,400,000,000,000 cubic feet. The river, therefore, drains off about one quarter of the en-

tire downfall, — an amount considerably larger than has been until now supposed. There are, however, three distinct classes of years well defined, — the extreme low-water years, when the discharge is only 11 trillions of cubic feet; the ordinary years, when it is 19½ trillions of cubic feet; and the great flood years, when it is 27 trillions of cubic feet. These differences imply corresponding variations in the amount of yearly rain, and perhaps spring from the same causes which occasion the secular oscillations of the great Northern lakes.

The observations of many years, without being absolutely decisive, go to show that the cultivation of the valley since 1819 has produced no appreciable effect on the discharge of the river.

It was necessary for the Survey to ascertain the amount of sediment contained in Mississippi water, and liable to deposition. A grand argument urged against the outlet system of protection was, that the water was charged with sediment to its utmost capacity of suspension; and that, if any water were drawn off by outlets, the velocity of the river would thus be diminished, and a deposit would consequently occur in the channel below. This assumption was put to a rigorous test, which resulted in the great discovery that *the water of the Mississippi is undercharged with sediment;* and that any apprehension of danger from outlets on the score of deposition of sediment is wholly groundless. Samples of water were daily obtained at three different stations, at different depths, for fifty-two weeks, and, at one station, daily during the whole of a second year, and also at other times and places. Careful analysis of these specimens established the truth above stated, and also disclosed the fact that the sediment in Mississippi water is, during long periods of time, by weight, in the ratio to the water of 1 : 1500; and by bulk, of 1 : 2900. Assuming this result to be correct, and the average annual discharge of water to be accurately estimated at 19½ trillions of cubic feet, it follows that 812½ billions of pounds of sedimentary matter, constituting a square mile of deposit 241 feet deep, are now annually transported in a state of suspension into the Gulf. When the swamps are reclaimed, the earthy matter now deposited on them will be carried along into the Gulf. When,

therefore, the four great swamps are thus protected, there will be an addition equal to one eighteenth of the matter previously transported. The amount, therefore, then borne into the Gulf will be annually 858 billions of pounds, constituting one square mile of deposit 254 feet in height. But, besides the matter in suspension in the water, a vast amount is also rolled along the bed of the stream into the Gulf. Of this, no exact measurement can be made; but, from the yearly growth of the bars at the mouths, it appears to be annually about 750 millions of cubic feet, which would cover a square mile 27 feet deep. The total yearly contributions, therefore, of the river to the Gulf amount now to a prism with a base of one square mile, and a height of 268 feet; and when the levees are perfected, they will amount to a prism of the same base, having a height of 281 feet.

The mean temperature of air and water was calculated upon a continuous observation of two years at Carrollton. The water was found to give a mean annual temperature of about 64° Fahrenheit, while the air gives a mean 4.5° higher. The water is warmest near the end of August, and coldest near the end of January; and the difference between these extremes of mean weekly temperature is about 46°. The corresponding air difference is only about 40°, showing that the water reaches greater extremes of both heat and cold than the air, and that the changes in the water are more uniform, more gradual, and later than in the air. These results, singular and interesting as they are in a scientific view, are also among the many new contributions to science made by this Report. A general deduction from the observations shows that the mean temperature of the water increases 3° in travelling the 750 miles of river channel between Memphis and Carrollton, while the corresponding air difference is about 8°.

The fact that the largest and most fertile portion of the natural banks of the river is for 1,000 miles below the level of the floods, has forced the settler to make it his first object to protect himself against them. The levee system is the only one which has ever extensively prevailed in practice; but that it has thus far failed to accomplish its design in any great degree, the record of the great floods plainly shows. This record

is complete for the present century, having been regularly, though loosely, kept from 1798 to the date of the survey. To convey an adequate idea of their terribly destructive character, we propose to give a short account of the June rise of the flood of 1858, one of the largest on record, and the one adopted as a standard by the Report.

The Ohio and Mississippi were in full flood, and the torrent which swept into the head of the alluvial region, by the bed and through the swamps, above Columbus, was of tremendous volume. For seven days it poured down 1,475,000 cubic feet per second. It inundated Cairo. It washed away miles of the St. Francis levees, and poured over into the bottom lands, already deeply overflowed from the April rise. So small was the actual reservoir capacity of that region, that the six great bayous and the St. Francis River channel were not sufficient to give water-way to the flood, draining back into the Mississippi; and so, for miles above Stirling, it poured over the banks themselves, washing away the remains of the levee into the river. After this, rolling like a great wave through the St. Francis swamp, it collected again at Helena, and burst forth with renewed fury over the lower country down into the White River swamps, and through the Yazoo and Tensas bottoms. The Yazoo basin, though returning to the Mississippi more than 125,000 cubic feet every second during the whole rise, was deeply inundated. Below Red River Landing the levees fortunately remained unbroken except at two points; but it was owing solely to the fact that the upland tributaries below the Ohio were all low during this great rise, that the whole lower country escaped general overflow.

Such are the gigantic floods against which protection is sought. To estimate the value of property destroyed by them is not possible. An approximate idea, however, may be formed from the fact, that in the Tensas bottom, which was only one of those flooded by the rise just described, it was calculated that the loss caused by the inundation of 1850 exceeded $5,000,000. So enormous is the devastation from this cause, that it is probable that the property destroyed by three or four floods is worth enough fully to pay for the protection of the whole valley.

We have now conveyed to the reader, we trust, a correct idea of the conditions of the problem to be solved. But at the beginning of the survey, the solution was impossible, in the then existing condition of hydraulic science. The first work to be done, therefore, was to collect data for the double purpose of establishing the science and of determining the facts upon which the solution of the problem of protection depends. A long account of the details of the various field operations, conducted by the Survey with a view to gauging the Mississippi, its tributaries, and its crevasses, is given in the Report. The thoroughness and extent of this work strike the reader with astonishment, and command confidence in results, based upon observation so wide. By methods which, so exquisitely do they display the minute and careful detail of the Survey, we had marked for quotation, but must omit for want of room, the daily discharge was measured for one year at New Orleans, and for another year both at Columbus and at Vicksburg. The number of floats daily noted was on an average about seventy-five, and called for the most persevering watchfulness on the part of the observers.

But great as was the labor in the field, it was trifling compared with that in the office. After accumulating a vast mass of facts and exact observations on the river, the next duty was to reduce and digest them. But owing to the state of science, this was more difficult than at first appears. To attempt to enumerate the various and complicated analyses detailed in the Report, would stretch this article beyond all reasonable bounds. As a single example of these computations, however, the method of deducing from the field measurements the discharge of the river *for a single day* will be described. It was necessary to plot the paths of all the floats; group them in the proper subdivisions; multiply the corresponding partial areas of cross-section, and take the sum of the results. As during a large part of the time the floats were necessarily observed at a uniform depth below the surface, — owing to the physical impossibility of observing floats enough to measure the velocity at all points of the cross-section, — this result needed to be corrected by multiplying it by the ratio between the velocity at that depth and the mean at all depths. But

the law regulating this change in velocity at different depths was unknown. Theories on that subject were not only conflicting, but utterly contradictory. To determine, therefore, the true form of the curve of velocity at different depths, which virtually expresses the law governing the action of the force of cohesion between the particles of a fluid in motion, a most extended series of special measurements was made, and the results analyzed by an exceedingly intricate process, furnishing perhaps the best example anywhere to be found of the Bernouilli method of generalizing natural phenomena, a process so long and involved that it much exceeds in compass and extent Dubuat's celebrated deduction of his formula for mean velocity, hitherto regarded as affording one of the best examples of this method. Suffice it here to say, that the form of the curve, which is a parabola, — the changes produced by variations in depth and in the mean velocity of the river, — the effect even of the lawless winds themselves upon its delicate adjustments, — were all pertinaciously hunted down, and the desired ratio deduced. The intricate nature of this analysis may be inferred from the following resulting equation, which is the expression of the ratio between the mean velocity five feet beneath the surface, and the mean of the mean velocities in all vertical planes across the river. It is equation (12), on page 263 of the Report, with a slight substitution: —

$$\frac{Um}{U_5} = \frac{Um}{Um + \left(\frac{1}{3} + \frac{(0.317 + 0.06\,f)\,(10\,r - r^2) - 25}{r^2}\right)\left(\frac{1.69\,v}{(r + 1.5)^{\frac{1}{2}}}\right)^{\frac{1}{2}}}.$$

By such exact methods the daily discharge, throughout the alluvial region, of the river itself, of its principal tributaries, and of its crevasses, was, for the floods of 1851 and 1858, so determined, that the quantity of water which would have been added to the river had no crevasses occurred could be for any point exactly calculated. A comparative analysis of the other great floods finally decided what should be viewed as the increased volume at each point to be guarded against, supposing the river to be confined to its channel throughout the alluvial region.

The next question, how much this added volume of water would raise the surface of the river, led to still more compli-

cated analyses of the relations existing between the slope, cross-section, and discharge of rivers; analyses which demonstrated how exceedingly erroneous were all previous formulæ and methods, but which were themselves perfectly successful. At every step of the process, the results were tested by exact measurements, and at all important points this was done repeatedly. The proof is so cumulative, that it is impossible to dispute it; but it is also so abstruse and extended, that, though it appears in table after table of the Report, it cannot be intelligibly set forth within the narrow limits of a review. One idea, however, is forced upon the mind in reading this part of the Report; namely, that the results, though very important for settling the problem under discussion, are not solely, nor even chiefly, important on this account. They have reconstructed the science of river hydraulics. A new and complete system of formulæ is given, derived from actual experiment, which renders it unnecessary hereafter, as heretofore, to grope blindly for empirical rules. A pretty illustration of this is a valuable practical discovery evolved by these formulæ. It has long been a desideratum among hydraulic engineers to deduce a normal ratio between some single velocity and the mean velocity at all depths in the same vertical plane. Applying the new formulæ to the algebraic solution of this problem, they indicate that the ratio — hitherto overlooked — of the *mid-depth* velocity to the mean at all depths, is the most simple of all such ratios; in fact, very nearly constant. The very experiments of European engineers, from which they failed to deduce such a ratio for practical use, confirm this discovery in the most complete manner, — a very beautiful example of the power of mathematical analysis, when applied to natural phenomena. But we must not dwell any longer upon these purely scientific merits of the Report; and we cannot leave the topic better than by quoting the modest words with which the authors themselves conclude this portion of their work, after giving a table of tests for their formulæ.

"This table furnishes the crowning proof of the exactness of the new formulæ as applied to water moving in natural channels. Joined to the two preceding tests, it establishes beyond reasonable doubt, first, that the same laws govern the flow of water in the largest rivers, and

in the smallest streams; second, that the new formulæ truly express those laws; and, third, that the formulæ heretofore proposed do not express them even approximately.

"The connection of the subject with such vast interests as those involved in the protection of the alluvial region of the Mississippi from inundation, has exacted the utmost care in its treatment. The measurements have been made with the greatest exactitude; experiment has been multiplied; the most rigid scrutiny has been exercised in the application of mechanical principles and algebraic analysis to the phenomena, and the newly developed laws are thus accompanied by a weight of evidence that establishes their truth. The formulæ by which they are expressed are therefore entitled to the confidence of practical men."

We now hasten to consider the efficiency of the various plans of protection against inundation, as developed by the operations of the Survey. It falls to the lot of few men, at one and the same time, to create a new science, and then to apply it to a problem of such magnitude. This double success, however, has been achieved by the elaborate investigation which has at last settled the question of river protection in all its branches.

"Three distinct systems," says the Report, "have been proposed for the protection of the bottom lands against overflow. These are: — First, to modify the actual relations existing between the accelerating and retarding forces in the channel, in such a manner as to enable the former to carry off the surplus flood-water without so great a rise in the surface as they now require. To this system belong cut-offs. Second, to reduce the maximum discharge of the river. To this system belong diversion of tributaries, artificial reservoirs, and artificial outlets. Third, to confine the water to the channel, and allow it to regulate its own discharge. To this system belong levees, or artificial embankments. Each of these systems has its advantages and its disadvantages. Before deciding, then, upon the best practical system of protection from the floods of the Mississippi, each system must be examined in respect to its feasibility, its dangers, and its cost, as applied to that river."

Each of these systems is thoroughly examined in the Report, and the conclusions arrived at have all the force of demonstration. Without attempting to give the arguments, we can state here only the substance of those conclusions;

and we shall comment upon the different plans in the order in which they are mentioned in the above quotation.

Cut-offs, as proposed by hydraulic writers, are not applicable to large rivers like the Mississippi. Their effects, when applied to a single bend of that river, have been accurately measured upon the Red River cut-off and the Raccourci cut-off, and also twice calculated analytically. The final result proves indisputably that they are absolutely pernicious, because they reduce the height above the cut-off only by increasing it below; and thus save one part of the valley at the expense of another part. The true effect of cut-offs on a river has long been disputed, but this conclusion is supported by such evidence that it puts the question forever at rest.

Diverting tributaries have been proposed, in order to protect the lower valley by diminishing the discharge in floods. The general principle on which the plan rests is unquestionably sound; but the question is, whether the practical application of this system here would produce results commensurate with the inevitable cost. The Report answers this question in the negative, and shows the project of diverting tributaries to be utterly impracticable for the Mississippi, because it would be so enormously costly.

The plan of reservoirs is to hold back, in the flood season, by systems of artificial lakes upon the tributaries, a volume of water requisite to reduce the flood level within the river banks, and to let it forth during the low-water season so as to improve navigation; and thus to secure a double advantage. This plan, admirable in theory, is of ancient origin, and has been much discussed by European engineers. Such reservoirs were actually constructed, as early as 1711, upon the Loire, and have since been advocated for their double benefit by Lombardini, Vallée, and other most eminent hydraulic engineers. One of the advantages claimed for this system, the improvement of low-water navigation, was foreign to the purpose of the survey, and has never been sufficiently investigated for the Mississippi to allow any decisive opinion to be formed upon it. The second, that of the effect of reservoirs upon restraining floods, has received careful attention.

This system is, obviously, not applicable to all rivers. The

valley, for instance, must be of such form that dams of reasonable dimensions may be built, which shall keep back the identical water which otherwise causes the flood. It is, in brief, essential, "that certain important tributaries, which drain relatively large portions of the basin, shall debouch near their mouths from narrow gorges where dams can be constructed at reasonable cost, and where artificial lakes can be formed without injury to other interests." These conditions, however, are the very reverse of those existing in the Lower Mississippi. The basin there is a vast plain. Its main tributaries are navigable streams, great arteries of commerce, far too valuable to be interrupted by reservoirs, even if it were possible. But to test effectually this plan it is necessary merely to consider the quantity of water which must have been held back in order to have protected the alluvial region from the June rise of 1858, which we have just described, and which may be regarded as a standard flood. During thirty-six days, the amount of water passing the latitude of Columbus exceeded by 648,172,800,000 cubic feet the maximum amount consistent with the safety of the alluvial region. Reservoirs large enough to keep back, in a single month, *six hundred billions* of cubic feet of water, must therefore have existed above the mouth of the Ohio in order to have protected the lower valley from that great flood. Where can such reservoirs be placed? The nature of the Upper Mississippi and Missouri basins is such as to make the reservoir system totally inapplicable to them. They must, then, be placed somewhere in the Ohio basin. Its northern slope, however, is too level. Its southern slope furnishes the only advantageous sites. But here the month's downfall of rain contributed to the June rise of 1858, as accurately determined by the Smithsonian observers, was only 4.5 inches; an amount which required, to be drained into reservoirs, an area of at least 90,000 square miles, *an area much larger than the whole region in question.* This result shows the reservoir system for restraining the floods of the Lower Mississippi to be a *physical impossibility.* Even if it were not so, the cost for protection against the June rise of 1858, according to the most moderate estimate, would be $215,000,000; and to provide against inundation from the lower tributaries

also, would cost a large additional sum. Thus, without questioning the advantage of the reservoir system upon certain Western rivers for certain objects, the Report demonstrates that the idea of so securing economically the Mississippi Delta against inundation is "in the highest degree chimerical."

This system has been advocated for the Mississippi Valley chiefly by Mr. Charles Ellet, who was formerly employed by the government to investigate the subject of protection, and whose report has been somewhat circulated in this country and in Europe. This gentleman framed a formula from very limited observations, and solved the problem by it, arriving at the conclusion that the levee system was virtually impracticable, and that reservoirs afforded the true means of protecting the country. Although the Report of Captain Humphreys and Lieutenant Abbot is remarkable for its non-controversial character, when we consider the large number of old theories it has demolished, it was evidently impossible to pass over without a complete refutation Mr. Ellet's work, contradicting as it did, in advance, the entire conclusions of their survey. It establishes, therefore, by actual measurements, that Mr. Ellet's formula is the worst formula ever proposed for its purpose; that his measurements from their paucity and hasty character led him into egregious errors of fact; and, finally, that his practical conclusions are totally wrong, particularly in regard to the reservoir system. The quiet way in which this task of criticism is performed in the Report is the only approach to dry humor in the book; and certainly stands in most striking contrast with the method lately adopted by the pictorial papers to refute a recent heresy of the same gentleman respecting the manner in which General McClellan ought to conduct the war.

The plan of outlets consists in reducing the level of the floods by drawing off the surplus water to the Gulf through other channels than that of the main river. The chief argument heretofore urged against it has been, that it will cause deposits in the channel by reducing the strength of the current, and will thus finally elevate, instead of depressing, the water level of the river, — a result illogically deduced from erroneous statements of facts respecting the Po. The operations of the Survey prove these arguments fallacious. They

show that it is a mistake to suppose that outlets are disadvantageous to the river; that the inevitable conclusion both from theory and observed fact is, that, so far as the river is concerned, they are highly useful; but that, from the difficulty of disposing of the water, from their cost, from the unavoidable result of destroying the navigation of Lakes Pontchartrain and Borgne, and from the danger of changing the main channel of the river, they are inapplicable to the Mississippi. That this last consideration is a real danger is proved by the Rhine, the Po, and the Vistula, in each of which the main channel has been changed by diversion of the current through an outlet.

We now come to the plan of levees, the sole remaining system of protection from river floods, and the Recommendations, the fruit of all these extended investigations. "It has been *demonstrated*," to use the words of the Report, "that no advantage can be derived either from diverting tributaries or constructing reservoirs, and that the plans of cut-offs, and of new or enlarged outlets to the Gulf, are too costly and too dangerous to be attempted." That of levees, however, subjected to a long and abstruse local analysis in the Report, is essentially simple, promptly repays investments, and may be relied on for protecting all the bottom-lands which are liable to inundation, from Cape Girardeau to the Gulf. The works will, it is true, be extensive and costly, and will require unanimity in action; but they will be effectual, for the conditions of permanency and success are now at last determined. We quote the following passage, the practical value of which will be fairly estimated in the Mississippi valley only. It is the short expression of the result of labors which, we may well congratulate our readers, will not have to be repeated. It contains the requisite heights to be given to the levees, down through the whole length of the valley, in order to *insure* the safety of the whole region. Our readers must, however, bear in mind, if they wish to ascertain the height of the top of the levee *above the ground* at any point, that the average depth during high water above the natural bank of the river in the flood of 1858 was about four feet, and hence that this number must, on an average, be added to the following numbers given in the Report.

"To secure this end [the protection of the alluvial region from inundation] in the most economical manner, the operations of this Survey indicate that levees should be constructed. Near the mouth of the Ohio, they should be made about 3 feet above the actual high-water level of 1858, which has been selected as the plane of reference, because more unvarying than the surface of the ground. The height above this level should be gradually increased to about 7 feet at Osceola. Thence to Helena, the latter height should be maintained. Thence to Island 71 the height should be gradually increased to 10 feet. Thence to the vicinity of Napoleon, it may be gradually reduced to 8 feet. Thence to Lake Providence, it must be gradually increased to 11 feet. Thence to the mouth of the Yazoo, it may be gradually reduced to about 6 feet, and should be thus maintained to Red River Landing. Between that locality and Baton Rouge, it should be kept uniformly about 4 feet, and below Baton Rouge about 3 feet. If the water-mark of 1858 be unknown at any locality, it may be reduced to any well-determined local mark by the table in Chapter II. The above estimate is exclusive of settling, and allows about a foot for possible rise above the height necessary for restraining the flood of 1858.

"It should be remarked that these heights are based upon the supposition of *absolute security*, so far as its conditions can be ascertained. In building the levees, it may be more economical to incur certain risks of inundation, than to expend so large an amount at once in the construction of levees. . . . . The data presented, and the principles so fully elaborated, in this Report, will render it easy for the engineers in charge of the work of construction to decide what degree of protection it is economical to secure. It should be remarked, however, that, below the upper limit of the influence of the Arkansas and White Rivers, it will be unsafe to make any material reduction in the above heights of the levees, computed with reference to restraining the flood of 1858."

As to the cross-section of the levees, the following proportions may generally be used: "The width at top equal to the height, — the outer slope 3 to 1, and the inner slope 2 to 1."

No precise estimates of the cost of perfecting the present levee system are practicable, until exact surveys are made through the whole alluvial region. An approximation, however, shows the cost not to be large, when it is compared with the size of the country, and the magnitude of the interests in-

volved. The steps in making this approximation we cannot follow in detail. It suffices to say that, to perfect the present system of levees to the full system which the valley demands, will cost about $17,000,000. If there were no levees in existence, it would cost about $26,000,000. The immense difference between $9,000,000, the intrinsic value of the existing levees, and the absolute cost of building the same, including the value of the insufficient levees destroyed and of the crops consequently lost, is a dead loss due to ignorance of the true principles of river protection, and to want of concert in construction. Were it possible to estimate this loss, it would teach an instructive lesson upon the value of union, and the need of a central government to devise, control, and execute such plans of internal improvement.

It is interesting to compare with the sum required to perfect the levees, the sum which represents the annual value of the land which will be thus reclaimed. The area of reclaimable land from Cape Girardeau to Red River is 19,450 square miles. It is safe to assume that one half of this area will become, when reclaimed, available for cultivation, with a value of not less than $25 an acre. That area, therefore, will be worth $160,000,000. Below Red River there are not less than 1,000,000 acres of alluvial land under cultivation, worth $100 an acre. This price, and it is not an extravagant estimate, gives, for the value of the plantations in that section, $100,000,000. We have therefore a total of 7,400,000 acres of land, worth at least $260,000,000, which will be rendered securely cultivable by expending the relatively small sum of $17,000,000.

But while such is the value of the land, the value of its annual produce presents a still stronger argument for the building of levees. Assuming the number of acres protected and made available to be only 7,000,000, each acre on an average produces a bale of cotton, worth in ordinary times $45. We have, therefore, for the value of the annual product of the alluvial lands, rendered secure and certain by a complete levee system, the sum of $315,000,000. The extent of injury resulting from inundation has already been indicated in the case of the Tensas bottom, where the flood of 1850 alone caused a loss exceeding $5,000,000.

Having now drawn from the Report a condensed account of the physics and hydraulics of the river, and having briefly noticed the various plans of protection, we take our leave of the subject, and pass on to the concluding topics of the Report, the Delta proper, the mouths of the river, and the means of deepening them.

The Delta of the Mississippi begins at the head of the Bayou Atchafalaya, the point where the first branch is sent off to the Gulf. A bayou, strictly speaking, is a waste-weir, a stream which at the flood water of the river is an outlet; and at low water a tributary, and often a mere dry bed. It is usually widest at the river, and flows into a swamp, which, when surcharged by a flood, becomes a lake, to be drained only by retroflowage through the same channel into the river. The term, however, is now frequently, as in the present instance, used loosely of any stream connected with the river. The Delta is naturally divided into four districts; the Atchafalaya basin, the Terre bone district, the La Fourche district, and the Pontchartrain district. The soil of the first district is above the level of the Gulf, but about one half of the total area of the last three is composed of sea marsh. The whole region is entirely below the flood level of the river, and is covered with alluvial deposit. It contains several lakes and bayous, whose real nature is shown by an elaborate examination of Bayou La Fourche. This bayou was early protected by levees, begun near its source on the Mississippi and gradually extended down its course; and it has presented a puzzling scientific phenomenon. While, at the point of efflux from the river, the levees have not been raised, because the high-water level of the river was sensibly constant, the high-water level of the bayou below has been steadily on the rise, and recently, near Lockport, at the observed rapid rate of two feet during seven years. This continued elevation of the high-water level has necessitated a constant increase of the levee heights on the banks, to the amount of several feet during the last thirty years. This peculiar action of the bayou has been a well-known subject for scientific discussion, but, prior to the measurements of the Survey, has never been satisfactorily explained. They, however, have overturned the usual theory of a channel

and point of efflux below the levees, gradually filling up by alluvial deposit, and furnished the clew which has led to the true explanation.

There is, and has been for ages, a natural diminution of the cross-section of the bayou as we approach the Gulf. The principles governing the flow of water, now developed in the Report and applied to this case, show that the natural channel was, before the building of any levees, insufficient to carry off the flood volume received by the bayou, and that nearly 8,000 cubic feet per second, two thirds of the total flood receipts of the bayou, must have formerly poured over the natural banks into the swamps. The levees have never yet been built high enough to correct this natural deficiency of cross-section, while their gradual extension down the bayou has slowly added to the difficulty, by increasing the distance to the point of practical escape for the extra volume. The remedy is to build the levees to a height which will enlarge the cross-section sufficiently to give the requisite discharge without overflow. The proper heights for this purpose are given in the Report. Thus the Survey has, almost incidentally, settled a question which, though probably before unheard of by most of our readers, has been in the lower valley a standing subject of anxious debate for many years.

The geological history of the river was too interesting a problem to be dismissed without notice, and some very ingenious speculations about it are offered in the Report. These speculations are entitled to great weight, coming from observers so cautious and thorough, and who will hereafter be regarded as unquestionably the great authorities upon all questions connected with the Mississippi. The hypothesis that an arm of the Gulf once reached nearly to the mouth of the Ohio, and that the mouth of the Mississippi was there, is untenable. Many considerations, which cannot be mentioned here, lead to the belief that the mouth of the river was originally situated not far probably from Plaquemine; and that its prolongation into the Gulf has therefore been only 220 miles. The slope of the bottom of the Gulf, upon which this advance has been made, is capable of being approximately estimated. At New Orleans it is 40 feet below the surface of the Gulf. The deep-

sea soundings of the Coast Survey show that, at the Head of the Passes, 95 miles below New Orleans, the old Gulf bottom is there 100 feet lower than the surface of the Gulf. From this point the slope must be still greater, since 11 miles from the bar of the Southwest Pass, or 28 miles from the Head of the Passes, the water is 900 feet deep. The present rate of progress at the mouth has been obtained by elaborate comparison of the progress of all the mouths, as shown by the maps of Captain Talcott, of the Corps of Engineers, U. S. A., made in 1838; and of the United States Coast Survey, prepared in 1851.

The yearly rates are as follows: —

Southwest Pass, . . .	338 feet.
South Pass, ...	280 feet.
Northeast and Southeast Passes	130 feet.
Pass à l'Outre, ...	302 feet.
Mean annual advance of the Passes,	262 feet.

The river is therefore building out into the Gulf new land at the mean rate of 262 feet every year. Assuming this mean annual growth as a basis for calculating the age of the Delta, we have the period of 4,400 years as the time required for the growth of the river 220 miles into the Gulf. It is interesting to learn that the Delta is therefore younger by several centuries than the world, a fact which, compared with some of the other stubborn calculations of geology, will probably delight those who advocate the chronology of history and its determination of the date of creation.

The practical importance of this slow yearly growth into the Gulf lies in its probable future effect upon the level of the river surface. By observation and calculation it is shown that an advance of the river 25 miles into the Gulf will be needed in order to raise the water level one foot at Fort St. Philip. At least five hundred years would be required to accomplish this result, even at the present rate of progress, while it is certain that the progress cannot be *more* rapid, and it is probable, from the great depth of the Gulf ten miles out, that it will be less rapid than at present. The protection of the entire river valley, it has already been shown, will add only one eighteenth to the sedimentary deposit of the river. The wild theories

sometimes advanced, of the march of the southern coast into the Gulf, creating there new countries, and destroying existing coast lines and harbors, are therefore now shown to be not only without foundation, but also laughably absurd. Before that day arrives, Lord Macaulay's New-Zealander will have a chance to investigate to his heart's content the topography of the ruins of London, and then travel to America and prove that the mythical city of New Orleans never existed.

The geological character of the region below the Ohio leads to the necessary inference that in former epochs the Mississippi must have been a clear stream, like the St. Lawrence, and not, as now, subject to floods. How was it transformed into a muddy river, liable to annual overflow? To this speculative inquiry an answer is proposed, setting forth a theory so ingenious and beautiful, and withal geologically so probable, that only the pressure of a more important practical subject reconciles us to leaving it, together with the topics of the possible separation of the branches from the river, and of the ancient geography of the Delta, without further notice. We now come to the last great operation of the Survey, the solution of the problem of deepening the mouths of the river.

Between Bayou La Fourche and Fort St. Philip, the Mississippi channel is nearly uniform. It has, at high-water level, a cross-section of 199,000 square feet, a width of 2,470 feet, and a depth of 129 feet in its deepest part. At low water these dimensions become respectively 163,000 square feet, 2,250 feet, and 114 feet. Twenty miles below Fort St. Philip, the river greatly changes, and acquires a width of 7,000 to 8,000 feet, a maximum depth of about 40 feet, and an area of cross-section of 250,000 square feet. It then divides into three branches, called respectively the Southwest Pass, the South Pass, and the Northeast Pass. The last sends off a branch called the Pass à l'Outre. A bar is formed at the mouth of each of these Passes, where the river meets the Gulf. During the low-water period the Mississippi discharges through the Passes about 300,000 cubic feet per second. Taking the Southwest Pass for an example, we find it to have a length of 17 miles; a mean width of 1,200 feet; a mean depth of 58.5

feet, and a maximum depth of 70 feet. These dimensions continue to a point 7.3 miles from the crest of the bar. Here the true mouth begins, having, on the crest of the bar, a width of 11,500 feet, a mean depth of 11.5 feet, and a cross-section of 132,000 square feet. Its inner slope falls off toward the river at the following mean rate per 1,000 feet: —

From outer crest for 1,000 feet,	nearly horizontal.
In the next 3,000 feet, . . .	0.5 foot.
In the next 17,000 feet, . . .	1.0 foot.
In the next 5,000 feet, . . .	2.0 feet.
In the next 9,000 feet, ...	7.0 feet.

The bottom then becomes horizontal. The outer slope is more abrupt, and we again quote a table to show its mean fall per 1,000 feet.

From outer crest, for 1,000 feet, .	10 feet.
In the next 3,700 feet, ...	20 feet.
In the next 38,300 feet, . . .	5 feet.
In the next 14,000 feet, . . .	43 feet.

The Gulf is, therefore, 1,000 feet outside the bar, about 22 feet deep; and at 4,700 feet, about 100 feet deep; and then goes on deepening to upward of 1,000 feet. These particulars about the Southwest Pass are given in order to convey a distinct idea of the river bars, which are similar at the other mouths. During the flood period of about six months, the water in contact with the bar is fresh out to the outer crest, and moves seaward rapidly. Beyond the outer crest, salt water is found below this fresh-water stratum, moving seaward with a mean velocity of about half a foot per second, *but in a plane not parallel to that of the river water*, and diverging oftentimes from it as much as 20°. During the low-water period, of about four months, the water on the bar is always salt, sometimes moving inward, sometimes outward, and sometimes remaining at rest. At the outer crest of the bar, when the tides are greatest and are rising, there is an inward salt-water current *at the bottom*, which turns outward with the tide. During the transition between the flood and low-water periods, any of these conditions may be found to exist.

Facts enough are now given to enable us to comprehend a brief statement of the true theory of bar-formation. Its beauty must charm even the most casual reader. The fresh water, flowing into the Gulf from the river, is specifically lighter, and rises upon the salt water at an angle which is inversely as the strength of the current. The lifting power of the salt water from beneath widens the current, and spreads the fresh water over the salt. Consequently vertical eddies are produced at the dead angle, where the river water encounters and surmounts the Gulf water. This stoppage of the river current, where the fresh water rises and spreads over the salt water, leaves, of necessity, the mass of matter, previously rolled along the river bed by the force of the current, to become stationary at this dead angle of salt water. A deposit of this rolling matter is therefore formed at this point. *This deposit is the bar.* The bar is not formed, as has been generally supposed, from the matter held in suspension, and thus borne down so many miles by the river. The river water, *being undercharged with sediment*, bears its whole burden to a greater or less distance out into the Gulf. But it piles up into a bar at the mouth of the channel the slow-moving mass rolled down upon the bottom, while the river itself rises above its bed, and floats away over the salt water, until it finally loses its identity among the waves of the Gulf.

With the statement of this simple theory, we must omit the vast array of actually observed facts which prove it, the modifying influences which affect it, and the many phenomena which are now for the first time correctly interpreted by it. We must also leave untouched the investigation of the effect of the winds of the Gulf upon the shape of the Delta, the level of the Gulf, and the formation and shape of the bars; and hasten to the practical results of this part of the Report, the plans for increasing the water depth upon the bars, and the recommendations for improving navigation over them.

The bars at the mouths of the Mississippi, it is clear from the explanation given, are always forming. Consequently they must be steadily removed by artificial means. The appropriations by Congress, thus far three in number, have failed to accomplish any permanent good, for the reason that continued

action, not spasmodic exertion, is requisite. Made at irregular intervals, their effects had time to disappear entirely in the intervening periods. In order effectually to deepen the water on the bars, a permanent sum must be appropriated, the interest of which shall suffice to pay for the required annual labor; or else an annual appropriation must be regularly made. If the money for this perpetual labor be annually provided in some way, — and the sum required will not be large, for it was found by actual experiment that upon the Southwest Pass a depth of 18 feet, when once attained, was maintained for one year at a cost of only $60,000, — the difficulty is substantially removed; for the principles which govern the problem are now clearly ascertained by the development of the laws which really control the formation of bars. But to render clear the principle upon which the plans of deepening the water on the bars are based, requires additional explanation. It is found that the outer crest of the bar of the Southwest Pass advances yearly 338 feet into the Gulf, upon a width of 11,500 feet, and a depth equal to that of the Pass; while the erosive power of the current opens a channel at the front of the inner slope of the bar, 1,200 feet wide and 338 feet long, to the same mean depth. It is this equal advance of the crest of the bar and its inner foot slope that maintains the general permanence of depth upon the bar. Had the erosive power been double that found existing, the equal advance of the crest and foot of the bar would have been attained at a lower point of the inclined plane upon which the fresh water rises upon the salt water; and a greater depth of water upon the crest would have resulted. The aim, therefore, of all the plans is the same, — *to increase this erosive or excavating power of the current relatively to the depositing action.*

"This may be done," says the Report, "either by increasing the absolute velocity of the current over the bar, or by artificially aiding its action. To the first class of works belong jetties and the closure of lateral outlets; to the latter, stirring up the bottom by suitable machinery, blasting, dragging the material seaward, and dredging by buckets. These plans are all correct in theory, and the selection from them should be governed by economical considerations."

After examining these various plans in detail, the Report concludes with the following words: —

"The plan of stirring up the bottom by dragging harrows or scrapers over the bar is, no doubt, the most economical and the least objectionable. As already shown, during the low-water stage, and part of each transition stage, there is often dead water or a refluent current on the bar. The operation should therefore be limited to the flood stage, during which there is an outward current on the bar. . . . . .

"In conclusion, it should be stated, that no plan whatever will prove of any material benefit to navigation, unless a permanent fund be provided, untrammelled by restriction as to the mode of expenditure, from which a sufficient sum annually can be relied upon for the continuous prosecution of the work, after as well as before the channel has been opened to the desired depth. The bar is constantly forming, and must therefore be constantly removed."

With these words the Report ends, and the task of the reviewer draws to its close. We learn from the publishers that only 1,250 copies of the book were printed before the types were distributed. So small an edition of so valuable a work must soon be exhausted, and can be reached by only a few of the persons who will wish to consult it. Indeed, it is expressly stated in the Annual Report of the Bureau of Topographical Engineers for the year 1861, that authority was obtained from the War Department to print only a limited number of copies, chiefly for distribution among the officers of the corps and others engaged in similar investigations. To make it as widely useful as possible, we understand that the extra copies have been largely distributed to libraries by the Bureau. While this course will make it in a measure accessible for special consultation by professional men, the smallness of the edition has rendered it the more necessary to review it carefully and at length in our pages.

The protection of the Mississippi valley from inundation, and the improvement of navigation by deepening its mouths, are two typical problems of internal improvement. No others are comparable with them in importance to that wide valley, which alone is larger than France, Spain, Italy, Germany, and Turkey, all taken together; and hardly to the entire nation. An annual produce of $315,000,000 depends upon the one.

The foreign, water-borne commerce of the whole valley depends upon the other. Prior to these surveys, both those questions were subjects of angry and ignorant controversy. This book sheds upon both the light of day. The practical value of its conclusions to all the arts of peace in the whole Mississippi basin cannot be calculated; and we must remember that the Mississippi valley is the broad field which must inevitably become the seat of empire for the country. Such is the value of this book to the pecuniary interests of the nation.

But this is not all. In determining these practical questions it has laid the foundations of a new science; and it has done so in a manner which will prevent it from ever being superseded, and which well entitle it to the motto borne upon the title-page,—the wise words of Franklin's letter to Abbé Souliave,—"I approve much more your method of philosophizing, which proceeds upon actual observation, makes a collection of facts, and concludes no farther than those facts will warrant." We doubt if any recent scientific work can present so long a list of brilliant discoveries and rich contributions to knowledge, which do honor to American science, and which are the legitimate results of a true method of philosophizing. The Delta Report cannot fail to give a wide reputation to the professional papers of the Corps of Topographical Engineers, a series of scientific papers of which this forms the fourth.

These investigations, so vast and so entirely successful, teach us three things. In the first place, they prove the value of that central government which makes out of thirty-four independent States one united nation, by showing how it solved in twelve years, both in their principles as well as their minutest details, the two great problems of river protection from overflow, and the deepening of water on the bars,—problems which had baffled all the efforts of four separate States for a century and a half. In the second place, they teach at every step of the process that it is almost a physical impossibility for the valley of the Mississippi ever to be politically divided. The power which rules at its source must hold the channel, the Delta, and the mouths. The current of the Mississippi is a bond, stronger than iron, to chain together all parts of its alluvial valley by the inevitable physical necessity of united

effort for protection against the floods, and by the fact that such enormous lines of continuous embankment can be built and owned only by one nation. And, finally, these successful operations, so momentous in their consequences, exhibit strikingly the usefulness of our regular army in time of peace. For all these triumphs of theoretic science and practical hydraulic engineering we are indebted to the labors of two officers of the Topographical Engineers of our regular army.

It was the fashion some years ago, among politicians of a certain stamp, to underrate the value of our army, apparently because they did not themselves live upon an Indian frontier, and had forgotten the early history of their country. But besides protecting our borders from Indian violence, a service always greatly under-estimated, the army could then, fortunately for us, be employed in conquering the forces of nature. We gained geographical knowledge of our country by the progress of detachments through regions which could be traversed in no other way. By it we made surveys which, while they opened a new land to civilization, gained the technical information required for the most stupendous engineering project known to the present age, the Pacific Railroad. Nor is the plan of that great work the only one of its kind for which we are indebted to officers of our army. We speak advisedly, when we repeat what, after special examination, was, in 1859, declared without contradiction in the United States Senate, to be true, — that no great work of public improvement in the United States had been conceived and executed without the aid of some member of this particular class. "They are the men, over this whole land, who have inaugurated the great works of civil engineering which have been successfully executed. They were the teachers." For instance, any one who will take the trouble to examine the facts will find that the railroad system now existing in the United States was initiated, the earlier surveys conducted, and the earlier works usually brought to completion, in the hands of military engineers. This is true in almost all the States, and it will be found that "their works of internal improvement were generally planned and conducted by those who either were at the time or had been military engineers." Nor is it in the department of engineer-

ing alone that American science is indebted to the army. To enumerate the modes in which it has advanced our knowledge of the geology, botany, and natural history of the country, would be to repeat what is familiar to special students of those subjects, though overlooked by the world at large. We can only add, that the Delta Report is the last, and certainly one of the most valuable, of the treasures which we owe to the labors of officers of the regular army.

These services, rendered by the officers of the army, illustrate well the theory of our government, which declares the ballot-box to be the true way to decide political disputes, and which uses its army, unlike those of Europe, not in suppressing popular freedom, but in enriching the nation by gaining bloodless victories over natural forces. All will welcome the day when we can return to this time-honored policy, and when our military engineers shall again descend the Mississippi with no hostile intent, but charged with the duty of completing the work of protection, by building that magnificent system of levees which the Delta Report projects.